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H04Q 7/36

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GB 2349045 A GB 2318947 A WO 99/40648 A1
WO 00/27148 A1

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On-Line - EPODOC, INSPEC, JAPIO, WPI

(54) Abstract Title
Applying downlink weights to an adaptive antenna array

(57) A base transceiver station 8 includes an adaptive antenna array for radiating a beam of energy 10 in the direction of a mobile station 12. The base transceiver station may estimate the position of the mobile station based upon estimates of both the angular spread of multipath signals received from the mobile and the direction of mobile relative to the base transceiver station. The angular spread and direction may be used to define a spatial sector in which the mobile is believed to reside and a set of downlink weights may be computed so that the antenna array produces a beam with sufficient angular spread to cover such a spatial sector. The downlink weights may be complex weights and may be calculated using discrete spheroidal prolate sequences.

FIG. 2

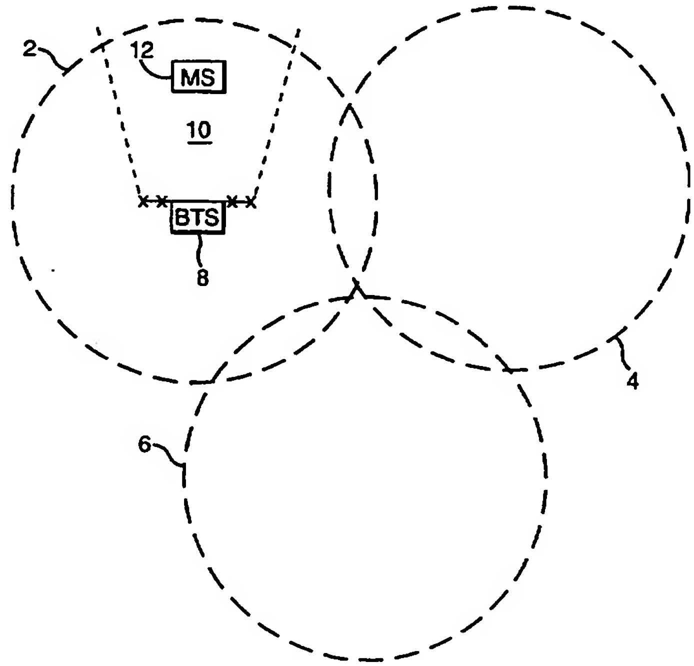

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FIG. 1

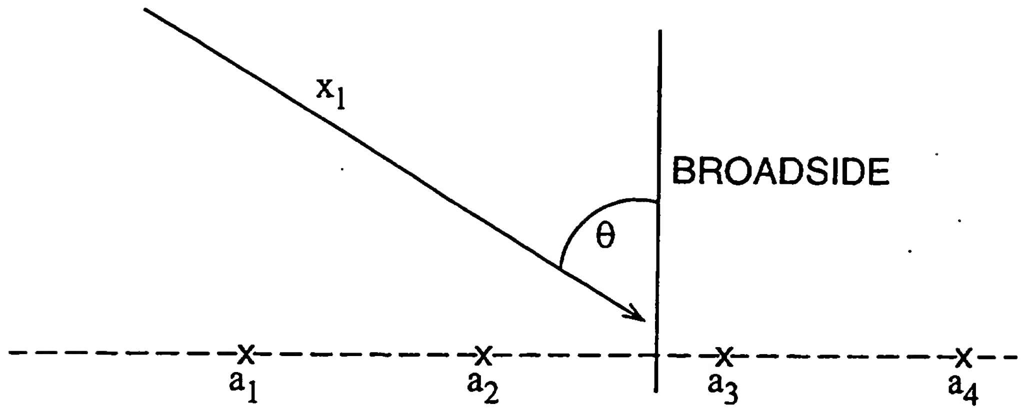


FIG. 2

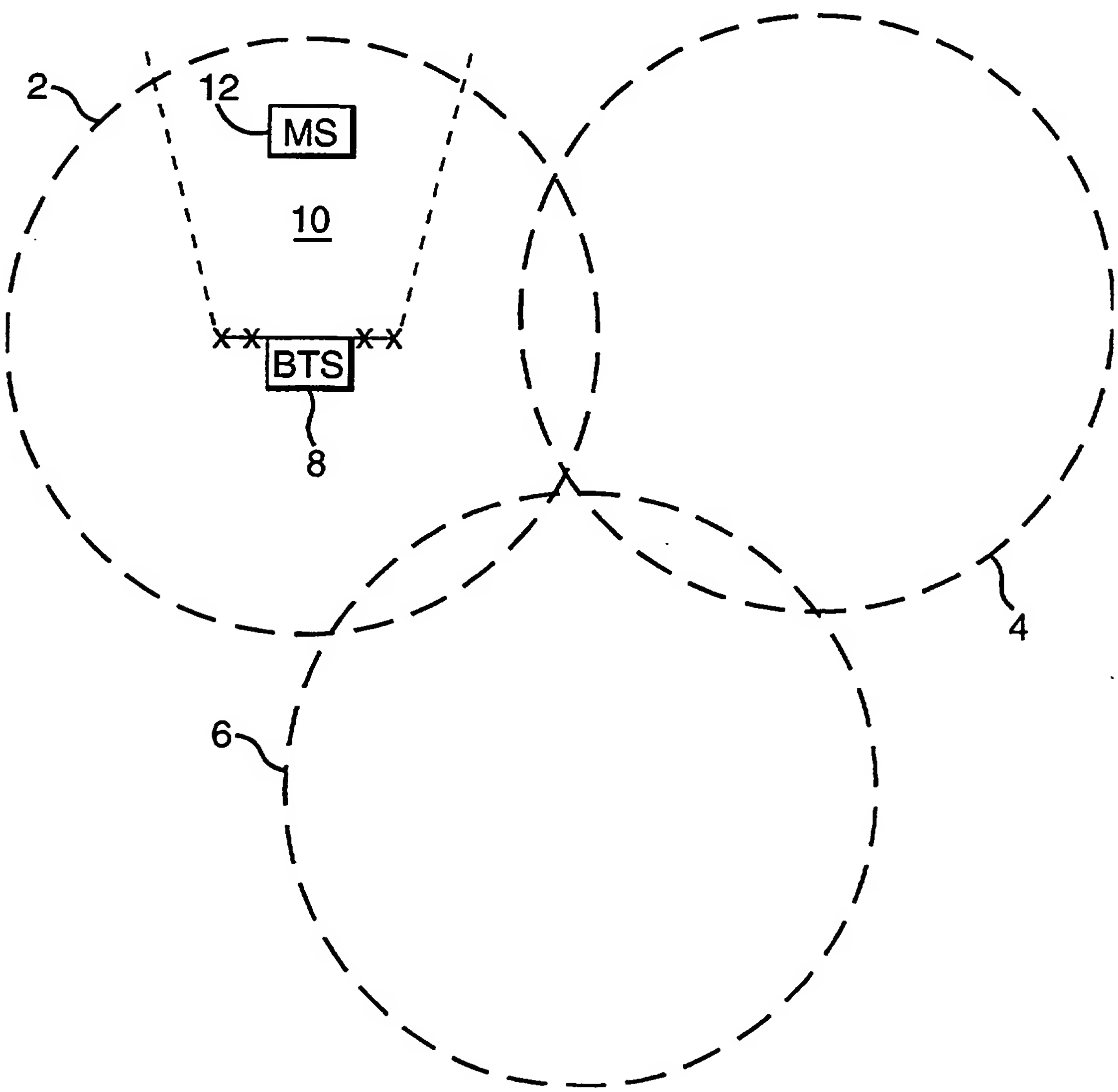


FIG. 3

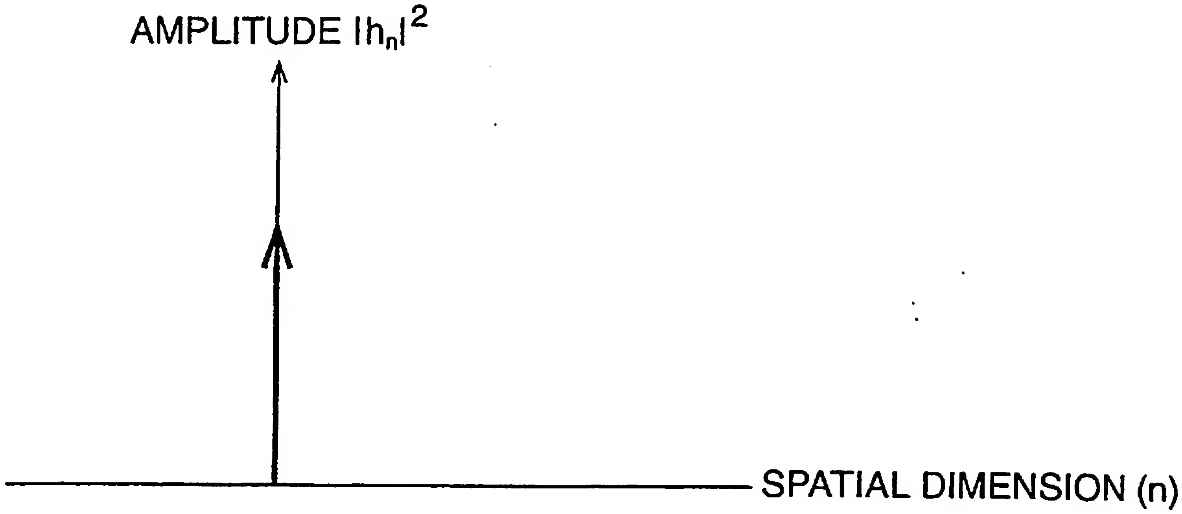

AMPLITUDE $|h_n|^2$
SPATIAL DIMENSION (n)

FIG. 4

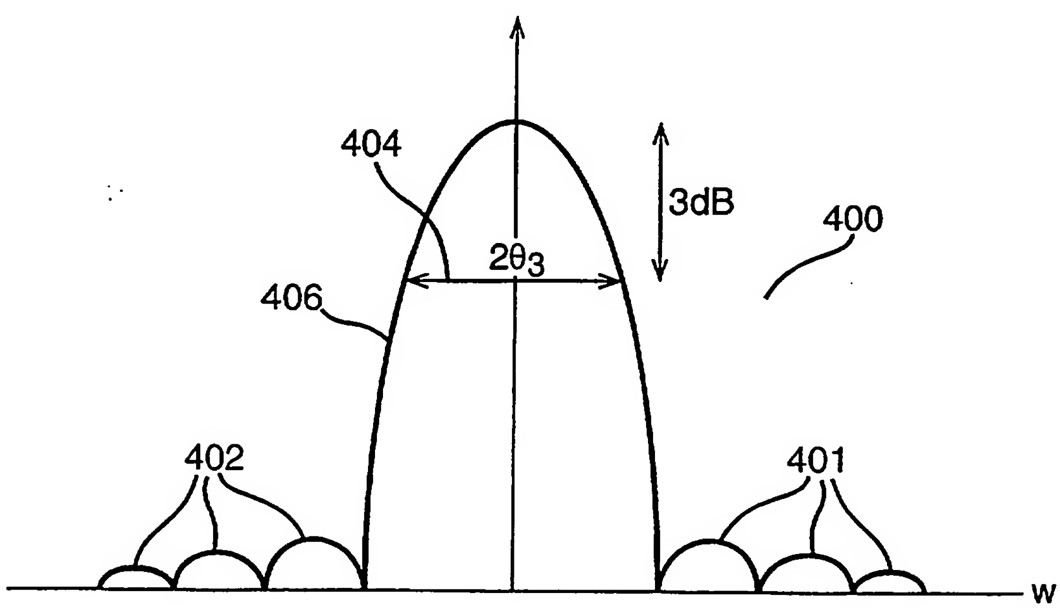

404
3dB
400
$2\theta_3$
406
402
401
w

FIG. 5

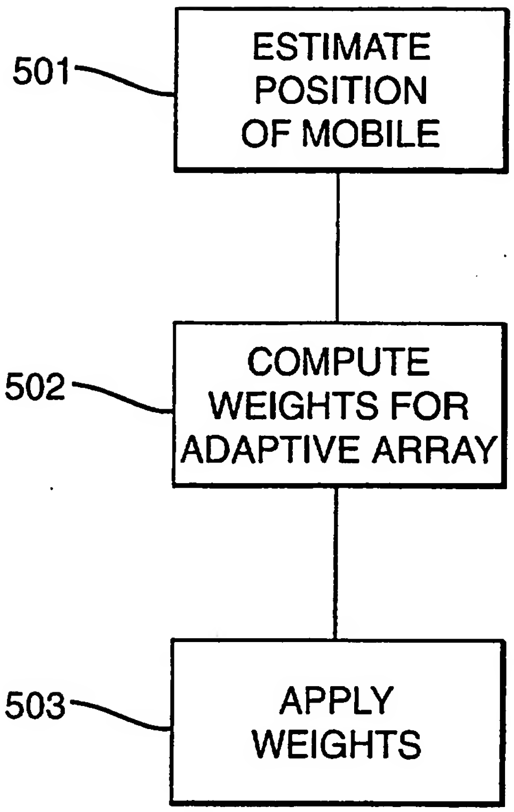
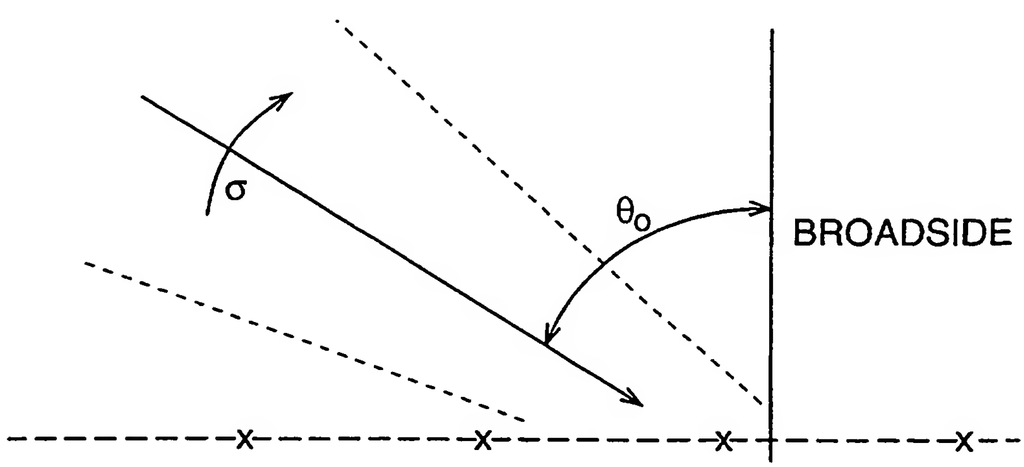

501
ESTIMATE POSITION OF MOBILE
502
COMPUTE WEIGHTS FOR ADAPTIVE ARRAY
503
APPLY WEIGHTS

FIG. 6


σ
θ_o
BROADSIDE

DOWNLINK WEIGHTS

This invention relates to downlink weights used in cellular communication systems, and more specifically to their computation for use with adaptive arrays in such systems.

In a traditional GSM standard cellular communications system, the reception of an incoming signal from a Mobile Station would be achieved at a Base Transceiver Station (BTS) by means of diversity reception. Each BTS would have two antennae and a receiver. The antennae would be spaced apart from one another. As such, an incoming signal would be received independently at each of the two antennae, the two received signals then being combined to produce a single received signal. In the scenario where the signal received at one antenna is very weak, for whatever reason, the fact that the signal received at the second antenna, which will ideally be stronger, is combined with that of the first strengthens the overall signal received by the BTS. This overcomes problems caused by signal weakness at one antenna due to such effects as obstructing structures.

Over the years the use of cellular communications systems has increased dramatically. As such, the point will be, and already has in some instances, reached where the number of users who can be readily supported by a network becomes a limitation of that network. One way to increase the maximum number of users that a network can support is to reduce the re-use factor of the network's frequency plan. Such things are known in the art, but will be briefly touched upon.

A cellular communications system comprises a number of cells, or areas, each served by a BTS. Each network is allotted a certain range of frequency within which it operates. In order to maximise the area of coverage which may be achieved using that set frequency range it is necessary to re-use frequencies in areas of the network where such re-use will not cause interference between cells. In order to ensure that interference is minimised, a frequency plan is used. A frequency plan is a plan covering the entire network which is formulated to ensure

that the frequencies utilised throughout the network are compatible with their surrounding frequencies.

If the re-use factor for a network is reduced, the compatibility of frequencies utilised throughout the network will suffer because frequencies will be re-used more often. This brings them into closer proximity with frequencies with which they may interfere than would be the case if a higher re-use factor were employed.

An alternative method of signal transmission and receipt to that of diversity reception, as detailed above, is the use of an adaptive array in the place of the previously used antennae. An adaptive array consists of a number of sensors which are typically set out in a linear equally spaced configuration, as may be seen in Figure 1. The spacing between each element of the array is commonly set around half the wavelength of the propagated signal. Each element within the array has a complex weight associated with it. This allows each element to be adjusted, in both amplitude and phase, to direct the beam pattern of the receiver (as detailed below) for example. As may be seen from Figure 1, incoming signal x_1 approaches the array at an angle of azimuth θ. Therefore the signal x_1 will reach array element a_1 prior to element a_2. Correct weighting of the array elements allows all the signals produced by the array to be combined coherently. The weights serve the purpose, in this example, of delaying the signal received at elements a_1, a_2 and a_3 until such time as the signal is received at element a_4, thereby allowing coherent re-combination of the received signals. Such adaptive array systems have been used previously in military and radar applications, wherein adjustments made to the outputs of the array, by tweaking the weights, will allow identification of the direction from which an enemy transmission is emanating, for example. This may be achieved by moving the focus of the beam pattern of the array and isolating the direction which produces the strongest system output.

In most of the current systems using frequency division duplexing (FDD), the BTS has no knowledge of the characteristics of the downlink propagation channel. If the network is not synchronous and moreover if it uses frequency hopping, the

BTS cannot plan for or accommodate the direction of interference causing obstructions. Such obstructions may be mobile, for instance motor vehicles in built up areas may cause interference.

In view of the foregoing it is apparent that there exists a problem in GSM standard cellular communications systems, in the provision of greater system capacity, in the reduction of interference, and in the combination of these individual problems. However, the problem to be solved is how to achieve such benefits in performance within the scope of the GSM standard.

This invention solves this problem by focusing a beam of energy radiated from the adaptive array (for the purpose of transmitting a signal to a mobile station or receiving one therefrom) in the direction of the main (strongest) components of the multipath signal received from the mobile station with which the BTS is to communicate. The above direction is hereinafter referred to simply as the direction of the mobile station. Such a situation is illustrated in Figure 2, which depicts three adjacent cells 2, 4, 6 of a cellular communications system, wherein the BTS 8 is focusing a beam of energy towards the MS 12. Such a procedure gives a marked improvement in the system performance over the techniques used currently, which include the radiation of energy in all directions from the array or the random choice of certain cell sectors to be excluded from the beam pattern. The second of these potentially isolates mobile stations within the excluded areas and is considerably less than desirable.

In order to direct a beam of power from an adaptive array it is necessary to compute a set of weights appropriate to the required beam and apply these weights to the signal to be radiated. In fact, a weight is applied to each element in the adaptive array and thereby applied to the signal. An exemplary beam 10 of radiated power may be seen in Figure 2 generally indicated by the broken line.

In view of the above required selection of weights to appropriately direct the power radiated from the adaptive array, the requisite task may be seen as that of synthesising an appropriate finite impulse response filter to produce the desired

beam pattern. The classical approach to this task would be to select the amplitude of weights from those of one of a family of well known windows often employed for such purposes. Such windows include those proposed by Bartlett, Chebyshev, Hanning, Hamming, Blackman, Kaiser, and of course the rectangular window which is the simplest window of them all.

In a situation where the direction of the mobile station is known at the BTS and there is a direct line of sight between MS and BTS, the ideal beam to be radiated by the adaptive array would look, as shown in Figure 3, like a spatial Dirac pulse. This indicates that, for the scenario where there exists fixed given radiated power, the best set of weights to use is the set which maximises the radiated power in the direction of the MS. As such, it would appear that the rectangular window is the most appropriate window to base the weights on as its frequency response has the narrowest main lobe of the available windows, as shown in Figure 4. The pattern of the beam of radiated energy would correspond substantially thereto.

There exist some major problems with the above described approach. Whilst it is certainly a sensible one there are two defects with it. Firstly, it takes no account of the level of interference created by the leakage of the transmitted power through the side lobes 401, 402 of the beam pattern as shown in Figure 4. This is a factor which must be considered, because it directly effects the overall performance of the whole network. The second defect subsists in that, in reality, the BTS estimates the direction of the MS from the uplink measurements i.e. measurement of the uplink signal. There is no definite reason to believe that this will provide an accurate estimate. Therefore, the optimality criterion in the choice of window will not necessarily be the peak amplitude, or the breadth 404 of the main lobe 406.

The situation becomes more difficult when line of sight communication between the BTS and MS is not possible. This occurs when the line of sight is blocked by "scatterers" such as buildings or even motor vehicles. When this occurs multiple copies of the originally sent signal may reach the receiver after having been reflected off of various scatterers. The different copies of the signal will inherently have taken differing routes to the receiver, thus they will arrive at different times.

This feature is known as "multipath" and the receiver utilises an equaliser to resolve the interference caused by this effect.

It is worth noting that the spread of paths coming into the receiver could be narrow or wide, depending upon the route taken to reach the receiver. The narrower the spread the better as the sector which each BTS must cover within a cell is reduced. As an example, a US city such a Boston, Massachusetts would provide for a narrow spread because it has wide roadways and reasonably regulated buildings. In contrast, an English city such as London would provide for the opposite, because it has very narrow streets and an almost random location of buildings. Additionally, the spread will vary with time, because of such features as moving vehicles acting as temporary scatterers etc.

It is thus clear that there are a number of problems prevalent in the improvement of system capacity and the reduction of interference in a cellular communications system by the focusing of a beam of radiated energy in the direction of a mobile station with regard to the base transceiver station of a cell.

The present invention addresses some or all of the above disadvantages.

The present invention provides, as claimed in the appendent claims a method of increasing cellular communications system capacity, wherein downlink weights applied to an adaptive array are computed adaptively. Adaptive computation of the downlink weights is the term used to describe those weights being calculated and adapted to cope with variations in the operational parameters of the system. An example of such variation may be an increase of the angular spread associated with a particular MS caused by the movement of mobile scatterers between the MS and BTS of the cell in which the MS is located. The weights would be recalculated (adapted) to ensure that the radiated beam still adequately encompasses the position of the MS.

The present invention also provides a method of reducing interference in a cellular communications system, wherein downlink weights applied to an adaptive array are computed adaptively.

This invention allows a beam of energy defined by the direction of a mobile station with respect to the base transceiver station of the cell within which it resides and the angular spread of that mobile station to be radiated towards the mobile station. Such a beam enables the receipt of signals transmitted by the mobile station to the base transceiver station, or the transmission of signals from the base transceiver station to the mobile station. The beam is focused adaptively in order to deal with mobile scatterers between the mobile station and the base transceiver station varying the width of the sector within which the mobile station is believed to reside. Hence, such adaptivity also accommodates for the reception of multipath signals at the base transceiver station.

In another aspect of the present invention there is provided an apparatus for facilitating the increase of cellular communications system capacity and an apparatus for facilitating the reduction of interference in a cellular communications system, both of which utilise adaptive computation of downlink weights to be applied to an adaptive array.

Additional specific advantages of the present invention are apparent from the following description and figures.

Figure 1 is an illustration of an exemplary adaptive array;

Figure 2 is an illustration of part of a cellular communications system depicting the radiation of energy from a base transceiver station;

Figure 3 is an illustration of a spatial Dirac pulse;

Figure 4 is an illustration of the frequency response of a rectangular window;

Figure 5 is a flow diagram depicting the method of this invention; and

Figure 6 is an illustration of the characteristics of the present invention.

The present invention is now described with reference to the accompanying drawings as detailed above.

The present invention addresses the problems in the art by, for a given emitted power from a BTS, maximising the energy radiated in a defined spatial sector of the cell, in which the MS should reside. As a result of this, the radiated power outside the defined sector is minimised thereby reducing interference with other users of the frequency spectrum and thus improving the overall network performance. More specifically, as the energy radiated is confined to a specific sector, the likelihood of interference outside that sector is reduced.

Referring to Figure 5, the method of the present invention is described. Function box 501 details the step of estimating the position of the MS in relation to the BTS. This is carried out at the BTS, which estimates coarsely the direction θ_0 of the mobile and its angular spread σ, i.e. the arc in which the mobile station position is expected, as shown in Figure 6. These two quantities define a spatial sector that contains most of the energy of the signals received from the mobile station (or reciprocally transmitted toward the mobile station). The sector can also be characterised by a spatial frequency f_0, and a beamwidth 2W, linked respectively to θ_0 and σ.

In function box 502, the adaptive array weights necessary to maximise the energy radiated in the spatial sector defined in step 501, and thus to minimise the energy radiated outside that sector, are calculated. These weights are a set of complex weights,

$$\{h_n\}(n=0.....N-1)$$

where N is the number of array elements.

Expressed mathematically the requisite task is to maximise the following ratio.

$$\lambda = \frac{\int_{-W}^{W} |H(f)|^2 df}{\int_{-1/2}^{1/2} |H(f)|^2 df}$$

where H(f) is the fourier transform of the sequence $\{h_n\}$.

The discrete prolate spheroidal sequences can be obtained as the eigen vectors corresponding to the (ordered) eigenvalues of the (N, N) matrix with elements:

$$\frac{\sin 2\pi W(m-n)}{\pi(m-n)}, m,n = 0........N-1$$

Maximisation of this ratio is performed using the first discrete prolate spheroidal sequence $\{V_n^{(0)}\}$ (n=0...N-1) as described in "Prolate Spheroidal Wave Functions, Fourier Analysis, And Uncertainty - V: The Discrete Case", D. Slepian, The Bell System Technical Journal, Vol. 57, No. 5, May-June 1978.

Application of this sequence provides, for a uniform linear array containing N elements, with a sensor spacing of a half a wavelength, the following set of complex weights:

$$\{h_n = V_n^{(0)} \exp(i2\pi n f_0), n = 0....N-1\},$$

where

$$f_0 = \sin\theta_0 / 2$$

This solution is only valid for a uniform linear array of N sensors, but extensions to arbitrary array geometry are possible. It is to be noted that this solution makes use of only the first discrete prolate spheroidal sequence. A more efficient spatial filter may be achieved by using the first K=[2WN]-2 sequences, where the bracketed term denotes the integer part of a real number, 2WN.

As explained above, the computation of the discrete prolate spheroidal sequences may be carried out through the eigen value decomposition of a matrix. If this facility is not available at the base station, it is possible to pre-compute the sequences for a given number of sensors N, and a discrete set of vector widths W, and store these values in memory at the base station. The amount of memory required to store these values would be small in size because the number of practical values of W is limited. For practical reasons it is not necessary to cover the whole horizon as regards the BTS, with a fine level of quantisation, thus the number of values of W will be limited. The sequence

$$\{V_n^{(0)}\}$$

is symmetrical, which also has a bearing on the memory required, i.e. the amount of memory required is smaller than it would be if the sequence were not symmetrical.

Function box 503 depicts the step of applying the weight set to the adaptive array in order to achieve the desired beam of radiated energy and enable efficient reception or transmission to or from the mobile station in question.

The parameter W is an operator parameter which is derived from the angular spread σ. It allows the operator to adjust the selectivity of the spatial filter. When the angular spread σ increases, the operator may want to increase W accordingly in order to keep track of all the multipath components of the signal (the spatial filter becomes less selective). Alternatively, when the angular spread decreases, the operator may want to decrease W accordingly in order to improve the sector isolation, i.e. the selectivity of the spatial filter. By virtue of this, the procedure is adaptive to the environment because it is dependent upon the angular spread σ. The angular spread will vary with time, it is also expected to be much greater in the case of small cells with a large number of interfering obstructions than in a large cell with near line of sight propagation between MS and BTS.

This invention has been described paying specific attention to a single cell scenario in a cellular communications system. However, it will be appreciated that this method can cover some or all the cells within a cellular communications system.

It will of course be understood that the present invention has been described above by way of example only, and that modifications of detail can be made within the scope of the appended claims.

CLAIMS

1. A method of increasing cellular communications system capacity, wherein downlink weights applied to an adaptive array are computed adaptively.

2. A method of reducing interference in a cellular communications system, whereindownlink weights applied to an adaptive array are computed adaptively.

3. A method according to either of claims 1 or 2, wherein an estimate of the relative position of a mobile station is made at a base transceiver station.

4. A method according to claim 3, wherein the step of position estimation comprises the steps of:

estimating a direction θ_0 of the mobile station with regard to the position of the base transceiver station; and

estimating an angular spread σ of the multipath components of the signals received from the mobile station.

5. A method according to claim 4, wherein the direction θ_0 and the angular spread σ define a spatial sector in which the mobile station is believed to be.

6. A method according to any of claims 1 to 5, further comprising the step of computing a set of weights to be applied to the adaptive array.

7. A method according to claim 6, wherein the weights are complex weights.

8. A method according to claims 5 and 6, wherein the weights are computed to maximise the energy radiated by the array within the defined spatial sector, and to minimise it outside that sector.

9. A method according to claim 8, wherein the spatial sector is also characterised by the spatial frequency f_0 and the beamwidth 2W.

10. A method according to any of claims 6 to 9, wherein the weights are calculated using the first discrete spheroidal prolate sequence.

11. A method according to claim 10, wherein the set of complex weights is given by

$$\left\{h_n = V_n^{(0)} \exp(i2\pi n f_0), n = 0.....N-1\right\}$$

12. A method according to any of claims 6 to 9, wherein the weights are calculated using the first [2WN]-2 discrete spheroidal prolate sequences.

13. A method according to any preceding claim, wherein the set of weights is applied to the adaptive array.

14. An apparatus which facilitates an increase in cellular communications system capacity, wherin the apparatus enables downlink weights applied to an adaptive array to be computed adaptively.

15. An apparatus which facilitates a reduction in interference in a cellular communications system, wherein the apparatus enables downlink weights applied to an adaptive array to be computed adaptively.

16. An apparatus according to either of claims 14 or 15, comprising, in the base transceiver station:

means for estimating the position of a mobile station;
means for computing a set of weights for an adaptive array; and
means for applying the set of weights to the adaptive array.

17. A method of increasing cellular communications system capacity, substantially as hereinbefore described with reference to figures 5 to 7 of the accompanying drawing.

18. A method of reducing interference in a cellular communications system, substantially as hereinbefore described with reference to figures 5 to 7 of the accompanying drawing.

19. An apparatus which facilitates an increase in cellular communications capacity, substantially as hereinbefore described with reference to figures 5 to 7 of the accompanying drawing.

20. An apparatus which facilitates a reduction in interference in a cellular communications system, substantially as hereinbefore described with reference to figures 5 to 7 of the accompanying drawing.

The Patent Office

INVESTOR IN PEOPLE

Application No:	GB 0011552.7	**Examiner:**	Jared Stokes
Claims searched:	1 to 16	**Date of search:**	21 November 2000

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Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): H4L (LDSG)

Int Cl (Ed.7): H04Q (7/36)

Other: On-Line - EPODOC, INSPEC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X,E	GB 2 349 045 A	(Fujitsu) See abstract, page 14 lines 22-30	1-3,6,7, 13-16
X	GB 2 318 947 A	(Motorola) See abstract	1,2,13, 14,15
X,Y	WO 00/27148 A1	(Nokia) See page 4 line 2-page 7 line 30, page 14 lines 35-39	X: 1-6,8, 9,13-16 Y: 7
Y	WO 99/40648 A1	(Arraycomm) See abstract	7

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		